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THE BIRTH OF SAFETY

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16. Abstract

A survey in the popular mode of the engineering safety considerations required for a space program.

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To the unenlightened their work would seem to be barbarism: through the vast gates opening onto the testing ground a new, uniquely green rocket is delivered, and from there they bring a heap of crumpled, crushed metal cut to pieces by the gas jets. /36*

These people, who at first glance seem to have such a merciless attitude toward space technology, are called safety experts. They investigate problems related to the safety of the rocket carriers and spacecraft; they test them and subject them to various stresses.

The engineer builders and engineer designers are always occupied with calculations for safety. Without such calculations one could not build a bridge or create a machine.

At the end of the last century, the French engineer Eiffel erected a remarkable tower in Paris, having planned it as the high point of technical achievements of his time. This tower — 7-1/2 thousand tons of metal structure rising to a 300 meter altitude — to this day remains a unique structure.

During the building of the tower skeptics predicted that the tower would collapse under its own weight, it would be destroyed by temperature variations, would be broken down into rubble by the wind. However, being the unique symbol of Paris, it stands to the present day.

It is true that todays rocket carriers are not so large as the Eiffel tower, but the cares of the designers are immeasurably greater. If one removes the cover from a rocket, then its entire power assembly — an azure interlaced network of framing and stringers — which is revealed is a fine spider web construction in comparison with the crude assembly of the Paris monument. One wonders how the construction can support such a weight. And in fact the forces acting on the tower are incomparable with the stresses experienced by the rocket.

*Numbers in the margin indicate pagination in the foreign text.

The modern spacecraft is, in essence, a vertical tanker: 85 to 90% of its weight is made up by fuel. Fuel and oxidizer in the tanks are under pressure. As a result, many elements of the rocket design also are subject to internal forces.

But the present violence of stress begins with the activation of the engines, when at will, literally like a genie from a bottle, tens of millions of horsepower are flung forth, thrusting the rocket high beyond the atmosphere. With an increase in velocity atmospheric resistance increases. The carrier with its useful thrust is caught in the vice of counter acting forces striving to hold it back. Vibrations are capable of loosening elements securing the structure, while shock forces, appearing during the passage through the sound barrier, stage separations in the break away of the nose compartment subject the entire internal workings of the rocket to stresses. Its cover and power assembly decrease the stability of the rocket as the result of aerodynamic heating.

Under such conditions, it would seem, a solid reserve of safety would have to be built into the rocket. But designers cannot permit this for a very simple reason: of the many hundreds of tons which are launched from the launch pad, only 1/30 of the initial weight enters orbit. Such is the cost of combatting the terrestrial gravity. Therefore an excessive increase in stability, particularly as the result of manufacturing massive devices, can "sit down" on all the useful load.

Excess reserves of safety, or, as the specialists say, "the coefficient of ignorance", in rocket-space technology was the object from the beginning of a merciless war.

Glance at the testing area, where the safety experts work, and become acquainted with the tasks which they solve.

The first impression is that one has literally entered the assembly workshop of a vast machine building factory: there are testing stands, assembly areas at various levels, sealings rising very high, and vast glass enclosed areas. And only having glanced at the gigantic metal time movers, one is cognizant of the fact that he has entered the kingdom of modern robots — the destroyers of machines. However the safety experts in their "destructive" work give an impression which is directly contradictory to that which forced the unemployed English weavers to destroy the mechanical looms. At the base of their labor lies a conscious intention — a striving to render rocket-space technology more modern and reliable.

The safety experts are basically young people. Among them there are candidates of science — yesterdays graduates of institutes, specialists who have recommended themselves as fruitful investigators. In fact, this surprises no one — a new field of technology requires an influx of young working people.

A few people work on the test stands, but the number of people here is less than one would think. Making manual measurements of deformations is a matter which is unpromising and unsafe, particularly when testing for breakdown. This work is carried out by automatic sensors. Glued to the particularly critical mechanisms of the rockets structure, they note the smallest deformations which arise during the creation of mechanical stress.

The classic example of the sensor is an ordinary wire put together in the form of a lattice and enclosed in a square of thick paper. This paper is glued to the surface of the part. Deformation of the latter during testing causes compression or stretching of the wire. As a result there is a change in its resistance to electrical current, which would then be recorded.

The operation of sensors of another type is based upon the piezoelectric effect — the appearance of electrical charges on the surfaces of certain di-electrical elements under the influence of their deformation.

At present the investigators have within their grasp many varied sensors which operate under various conditions and which differ from the mentioned wire type in approximately the same manner as the platinum standard meter differs from the wooden school ruler. However, the safety experts do not scorn the use of the cycloptic form of manometers and other measuring devices.

During tests there are instances when it is not sufficient to know that the device undergoes deformation or breaks down at a given stress level; it is also necessary to observe how this occurs. Then television cameras and special types of movie filming are used.

Now preparations are being made to test a stage of a rocket carrier. All about it, in the service areas, people in blue coveralls are finishing the job of attaching the sensors, from which variously colored wires lead away.

The wires are gathered together in bundles and are attached to multi-branched cables running into the next room, where a special computer center is set up. Here the results of the measurements are recorded and processed. This is an automated process. The computer center can simultaneously serve several stands, testing installations and chambers.

The stands and installations are joined together in a complex, but a territorial concentration of these, let's say in a single building, is forbidden, inasmuch as the stand for dynamic tests, for example, would "unnerve" its outwardly calm neighbor — the static stand, while the chamber for shock tests is desirably placed even more further away and deeper down. However, for a number of tasks, it is necessary to create simultaneously various types of stresses and in that case one is forced to put everything together however incompatible.

The safety experts work in close association with the designers, metallurgists and technicians. According to the recommendations of the safety experts, in weak places the designer of the rocket apply an additional layer of strengthener, taking away excess weight where this is possible. According to their conclusions an ordinary pipe, for example, can be replaced by a three layer pipe, inasmuch as the latter "works" better at a bend. At the demand of the safety experts a search is made for new materials and a new technology for finishing parts is developed.

The safety factor calculations of the design are based on general methods of the theory of elasticity, the theory of plasticity, the theory of casings, and structural mechanics. Great development of these scientific disciplines has been obtained in relation to the requirements of solving a number of specific tasks of design set forward by aviation. Rocket-space technology /37
has always used and still uses the vast experience of aviation design. This is explained by the commonality of many problems, specifically those which pertain to creating designs with a great level of extension, designs, a significant

part of whose volume and weight is extended on fuel. It is interesting to note that in the future, in connection with the creation of space transport systems, the multifaceted application of the union of aviation and astronautics promises to become an even more tenacious one.

Among certain readers, obviously, this question may arise: why, having a basic scientific-theoretical base which enables one to make necessary calculations for safety, why then do the designers still test? Having made calculations for safety, it would seem that one could select materials with the desirable mechanical characteristics and then create a rocket. In reality, everything is posed in a somewhat more complex fashion.

Take merely the mechanical characteristics of materials — resistance to compression, warping, crowding, etc. As it turns out, these are not determined for all materials, and even if they are determined are not always adequately accurate. Obtaining accuracy, let us say, can satisfy the design of a metal cutting machine tool, or a tractor, but not the designer of rocket-space technology. And everyone of course knows that lately many new materials have come into use.

This is why the creation of test designs is preceded by many laboratory tests of models with the goal of comprehensively checking their mechanical properties. This particularly pertains to new materials.

Let's say that we have determined the mechanical characteristics with the maximal possible accuracy and have collected the necessary statistics. But this may prove to be inadequate for preparing a design optimal with respect to stability and weight, inasmuch as stability of a genuine device invariably differs from that of models. Here, inhomogeneity of internal structure has an effect, as do various effects caused by errors in technology. Additionally, the materials used in the structure have to be processed and put together by various means. This also has an extremely significant influence on their properties. Thus, when preparing thin walled coverings, tanks, and other containers, welding is widely used. But welding, even if it is carried out by the most modern methods and by the most skilled craftsmen, unavoidably leads to the appearance of microcracks and internal stresses due to heating of the metal and subsequent cooling. Welding also leads to such an unfavorable phenomena as distortion, deformation of a part as the result of residual stresses. In steel pipes, for example, the location of the weld is the site of a concavity, while in aluminum pipes, on the other hand, there is a convexity. Bolted joints, glued joints and calmped joints all have their shortcomings.

Thus, the theoretical model used for planning is based upon assumptions, and to some degree is an idealized representation of a genuine device. Calculation methods do not make it possible to take into account all of the varied factors which influence its actual capacity. The more objective the stability of a device when it is made in metal, to wit, can only be determined in the process of testing.

Of course, tests carried out on models are not excluded. They are widely used where they permit a decrease in labor expenditure and cost of testing. However on models one does not always succeed in duplicating all of the stresses experienced by the actual device. Additionally, their manufacture frequently requires quite complex mathematical calculations.

Flight in space, and the right of a completed device to experimental flight is received only following rigid testing of its double on the Earth. And that part of the flight model which returns from space (the launch apparatus of the spacecraft, the returnable apparatus of the automatic rocket, which delivered a sample of soil from the Moon), always is given over to the safety experts.

Testing elements of the rocket carrier and space apparatus designed for various purposes for safety is carried out on test stands for static and dynamic testing.

Stands for static testing enable one to create internal and external surplus pressures, longitudinal and transverse concentrated forces and warp moments, and also certain temperature regimes.

Testing with internal excess pressure is usually conducted hydraulically: the internal area of an object, for example a fuel tank, is filled with a liquid to the point at which internal pressure still does not reach an assigned value or the device does not break down.

Equally distributed external stress can be created by placing the object in a container filled with liquid under a certain pressure. For creating the necessary pressure a vacuum means is used, pumping the air out of the internal cavities of the object being tested.

Axial stress is obtained by the aid of hydraulic force activators. For more accurately determining breakdown stress during static tests, heating the device is occasionally simulated.

The test run through the test building is done at the moment when the signal is given for everyone to leave the room. Standing beside the testing devices during the tests is categorically forbidden.

Tests are observed by specialists from a room reminiscent of a command post. Here, alongside the control boards, television screens, etc. a group of engineers is located; in accordance with a worked out plan these engineers will conduct tests of the various stages of the rocket carrier.

Various services report their preparedness. The computer is activated; thousands of sensors feed information concerning all parameters reflecting what is occurring in the object to the computer. Signals flash on the control boards, by the aid of which the operators control the test equipment.

Through the thick glass of the control room one can see the rocket enveloped in a network of wires. At various points on its surface, on the most important parts, the lenses of television and movie cameras are focused.

The test supervisor, a young doctor of science, approaches the microphone. The tests are begun.

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